

Experience in Application of “JET Grouting” for Installation of Substructures of Estates

Galina G. Kashevarova¹, Oleg Makovetsky², Ilgiz Khusainov³

Perm National Research Polytechnic University, Perm, Russia

*1ggkash@mail.ru; 2oleg-mak@inbox.ru; 3ihi888@mail.ru

Abstract

The purpose of this paper is the acquisition and analysis of empirical data during the stabilization of foundation soil by the application of “jet grouting” method.

The object of the research is the installation of the foundation plate base under seismic forces at the construction of a new stadium of the football club “Krasnodar”.

Before soil stabilization there was foreseen in-situ production work in arbitrary areas of the construction site. On the test work sites technological parameters of grouting were determined, with the application of which the actual diameter of the elements in all engineering and geological elements would be definitely higher than 1200 mm.

The paper deals with a question of jet grouting method application to decrease the possibility of vibroliquefaction and vibrocreep of tight silty water-saturated sands and high porosity of brown semisolid clays. The advantages of “jet grouting” are shown in comparison with the installation of pile foundation consisting of bored elements. The paper contains the equipment and methods, used to determine the compressive strength and stress-strain modulus of the soil-cement samples of the stabilized soil (soil-cement). The quality control program was created for jet-elements quality control during the process of foundation stabilization. The physical and mechanical properties of separate soil-cement elements were determined.

Soil stabilization with jet-elements has brought about the effect of soil squeeze reduction and possibility limitation and the absolute value of its volume strains under the influence of the seismic wave. Under the circumstances there are no such phenomena as “vibroliquefaction” and “vibrocreep”.

Keywords

“JET Grouting”; Compressive Strength of a Soil-Cement Element

Introduction

Jet geotechnology, known as “Jet-grouting method”, is an advanced research field in modern geotechnics. Application of jet grouting has the capability to create homogeneous foundation soil with the pre-set physical and mechanical properties, and provides a high serviceability. Furthermore, in comparison with

traditional design considerations, for example, application of bored piles, operation time and base preparation cost decrease. The construction method of jet grouting makes it possible to control compression zones of a base and modify its properties at the best depth range. This technology has been applied in Russia and Europe during the construction of such large sports structures, as stadiums which belong to the projects of enhanced responsibility (Broyd, Zege, 2004, Malinin et. al., 2010, 2011, Ter-Martirosyan, 2010, J.C.W.M. de Wit, Bogaards P.J., Lannghorst, 2007).

One of the examples is the construction of a new stadium of the football club Krasnodar, the site of which is situated in the city of Krasnodar, in Prikubansky interurban district. The terrain of the construction site is relatively flat. The absolute marks of the ground surface range from 27.2 to 28.4 m.

Within the limits of the soil column, studied during soil investigation (to the depth of 40m), 7 engineering geological elements were separated: EGE-1. hard loam, collapsing ($E=12.4$ MPa); EGE-2. semisolid loam ($E=16.5$ MPa); EGE-3. silty sand, tight ($E=28$ MPa); EGE-4. semisolid clay ($E=14.9$ MPa); EGE-5. stiff loam ($E=12$ MPa); EGE-6. medium sand, tight ($E=34$ MPa); EGE-7. gravel sand, tight ($E=41$ MPa). The seismic activity at the construction site according to the map OCP-97B in terms of soil conditions is 8 points (CP 22.13330.2011, Nazarov, Rehbinder).

At the stage of analysis on the stadium building-up documentation, the following main peculiarities of its structural layout have been found: the essential nonuniformity of loads on foundation and that the tolerances of settlement between the blocks of the stadium must be not more than 2.5 cm.

The analysis of engineering and geological conditions of the site with regard to its seismic activity showed that the main problems of the site are the possibility of vibroliquefaction and vibrocreep of the layer of tight silty sands EGE-3, and high porosity of the layer of

brown clays EGE-4 at the earthquake intensity of 8 points.

Therefore, the necessity of foundation grouting is determined by the objective to achieve stiff characteristics of the foundation, which complies with the requirements, imposed to the construction design of the stadium with regard to Relative differential settlement, and potential possibility of vibroliquefaction and vibrocreep of the layers EGE-3 and EGE-4.

According to the comparison between two variants of securing serviceability of the foundation plate base under seismic forces: 1) installation of pile foundation consisting of bored elements, with the length of 15...20 meter and 2) solidification of layers EGE-3 (water-saturated sands) and EGE-4 (semisolid clays) by jet grouting, the second variant was chosen based on the cost and operation time (Khusainov I.I., Kashevarova G.G., Makovetsky O.A.).

Measures for decreasing deformations of foundations and their influence on structures are regulated by the normative requirements which specify that the design of soil solidification should make provision for the test and production work, moreover, slurry compositions for soil solidification by injection method and physical and mechanical properties of soils should be specified according to the results of their solidification in laboratory or field conditions.

Quality Control Program

The quality control program was created for jet-elements during the process of foundation stabilization, which included: determination of the best process variables to secure the guaranteed diameter of a jet-element in all engineering and geological elements, and also determination of physical and mechanical properties of the obtained material (soil-cement).

During in-situ production work, the following compulsory controlled parameters were accepted: diameter of the elements-not less than 1200mm; compressive strength on the 28th day-not less than 4 MPa.

In accordance with the program, on the construction site there were performed four soil-cement elements with Jet-2 from the ground surface (absolute mark-26.6 m) at the depth of 13.0 m (Fig.1).



FIG.1. TEST SITE WITH EXCAVATED ELEMENTS

The drilling depth was determined on the basis of engineering and geological conditions of the construction site. The elements were performed with the cement consumption of 600, 650, 800 and 900 kg, for one running meter of the stabilized soil. The technological parameters of grouting are given in table 1, and the layout of the elements is shown in Fig.2.

TABLE 1. TECHNOLOGICAL PARAMETERS OF GROUTING

Description	Unit of Measurement	Ø1200
Cement consumption for 1 rm	kg/rm	600, 650, 800, 900
Water consumption for 1 rm	l/rm	600, 650, 800, 900
Grout pressure	atm	450
Air pressure	atm	8
Quantity / diameter of nozzles	pcs/ mm	2/3,0
Drill rod rotation speed	rpm	32
Pulling speed	stroke/rm	25
Stroke length	cm	4
Injection time	sec/stroke	4,8

After the development of strength of soil-cement (aged 7 days) the performed elements were drilled in order to determine their actual diameter. With the consumption 600 kg/m, the diameter with 1000-1200 mm fails to adequately provide for the parameters of an element required for the soil reinforcement. While the work was performed with the cement consumption of 650, 800, 900 kg/m, the actual diameter of the elements in all engineering and geological elements was definitely higher than 1200 mm.

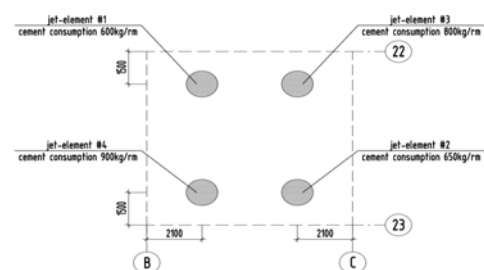


FIG.2. LAYOUT OF JET-ELEMENTS

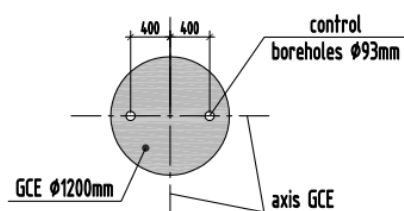


FIG.3. LAYOUT OF CORE SAMPLING DURING CHECK BORING OF BOREHOLES

Then check on boring of the tested soil-cement elements with core sampling was performed for the following laboratory tests. Core sampling, transportation and storage were performed in accordance with GOST 12071-84. From each element 12 samples of soil-cement were taken from the depths of 2.0; 3.0; 4.0; 6.0; 7.0; 8.0; 9.0; 10.5; 12.0 12.5 m from the soil surface (Fig. 4).

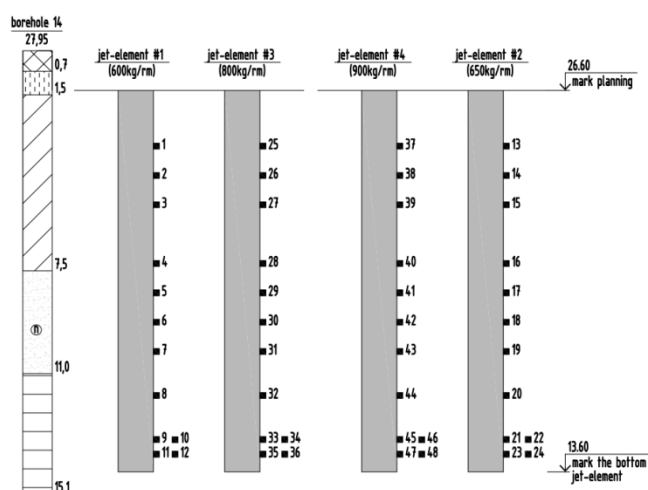


FIG.4. LAYOUT OF CORE SAMPLING IN DEPTH OF A BOREHOLE

The selected samples of the stabilized soil (soil-cement) were tested at the hardening age of 7 days and 14 days. Determination of compressive strength ($R_{compr.}$) and stress-strain modulus (E) were performed on the universal testing machine Zwick2-250, in accordance with GOST 21153.2-84 and GOST 28985-91. Statistical processing of the test results were able to define the mean values of the soil-cement compressive strength and stress-strain modulus, materialized in each engineering and geological element with different cement consumption values for one running meter. The soil-cement compressive strength ($R_{compr.}$) is within the range: 3.2...5.3 MPa for EGE-2 (loam); 8.0...9.0 MPa for EGE-3 (sand); 3.4...3.8 MPa for EGE-4 (clay). The soil-cement stress-strain modulus (E) is within the range: 1.5...2.0 HPa for EGE-2 (loam); 4.0...4.4 HPa for EGE-3 (sand); 1.5...2.0 ГПа for EGE-4 (clay).

The characteristics of soil obtained in the course of investigation on the test site, were used for development of the project design for the new stadium construction making it possible to control compression zones of a base and modify its properties at best depth range.

The improvement of physical and mechanical properties of the foundation soil was achieved by installation of "geomass" in the base of the plate- soil-cement reinforcing elements with the diameter of 1.3...1.5 m, with the space between the axes of 2.5...2.8 m. In this case, soil-cement elements work in a unified mass with the surrounding soil under the whole surface of the plate, and are not considered as a pile element, delivering the load on the underlying layers with its tip.

Results and Conclusion

The physical and mechanical properties of a separate soil-cement element were determined: density of the material = 23...25 kN/m³; design compressive strength $-R=3.5...4.0$ MPa; stress-strain modulus $-E=350...400$ MPa.

The represented strain characteristics of such geomass considerably increased. Specifically, the total strain modulus has increased by the values $E=60.0...80.0$ MPa as compared to the values of the strain modulus of natural soil $E=15.0...25.0$ MPa.

Installation of the base reinforcement, according to the standard calculation, leads to decrement of the effect of seismic forces on the structure. The presence of the regular grid of reinforced elements with the higher speed of S-wave transmission, as compared to the natural soil, resulting in considerable energy dispersion in them (elements), and the wave impact on the soil, protected by the elements, is minimal.

At the same time, installation of such vertical reinforcing elements has brought about the effect of soil squeeze reduction and possibility limitation and the absolute value of its volume strains under the influence of the seismic wave.

Under the circumstances there are no such phenomena as "vibroliquefaction" and "vibrocreep".

After the work on soil stabilization at the eight construction sites was completed, the geometric properties of the reinforcing elements and coring more than 90 samples of the material (soil-cement) were subjected to control.

The results of the analysis proved the design consideration to be correct.

To sum up, installation of soil-cement reinforcing elements has considerably increased the serviceability of the foundation by means of increasing its strain characteristics and active protection of soils from the influence of the seismic vibrations, providing the safe operation of the sports structure.

REFERENCES

- Broyd I.I. Jet Geotechnology: Teaching Guide. M: Publishing House of the Association of Construction Institutions of Higher Education, 2004.
- CP 22.13330.2011. Building and Structure Foundations. M FSUE Centre of Construction Design Products, 2010.
- J.C.W.M. de Wit, Bogaards P.J., Lannghorst and Others. 2007. Design and Validation of Jet Grouting for the Central Station Amsterdam, Proc.14th European Conference on Soil Mechanics and Geotechnical Engineering, Madrid Vol. 3: 1299-1305.
- Kashevarova G.G., Trufanov N.A. Chislennoe modelirovanie deformirovaniya I razrusheniya sistemi "Zdanie-Fundament-Osnovanie" [Numerical Modeling of Deformation and Failure of the System "Building - Foundation - Soil"] Monograph. Ekaterinburg-Perm: UrO RAN, 2005, 225s.
- Kashevarova G.G., Smetannikov O.U., Zobacheva A.U. Study of Possible Application of Different Design Models of Foundation - Soil System for a Pile-Raft Foundation of a High-Rise Building. International Journal for Computational Civil and Structural Engineering. Moscow – USA: ASV. 2009. V. 05. No 1-2. 45-56.
- Khusainov I.I., Kashevarova G.G., Makovetsky O.A. Comparative Analysis of Experimental and Estimated Jet Grouted Soil Mass Deformations. International Journal for Computational Civil and Structural Engineering, 2012. Volume 8, No 2, 126-132.
- Malinin A.G. Struinaya Cementaciya Gruntov. [Jet Grouting Soil]. Moscow: OAO "Stroiizdat", 2010.
- Malinin A.G., Gladkov I.L. (2011). Experimental'nie Issledovaniya Diametra Gruntocementnih Kolonn V Razlichnih Gruntovih Usloviyah. [Experimental Studies of the Jet Grouting Columns Diameter in Different Soil conditions]. Osnovaniya, Fundamenti I Mehanika Gruntov, No 3.
- Makovetsky O.A., Zuev S.S. Obespechenie Eksploatacionnoi Nadezhnosti Podzemnoi Chasti Kompleksov Zhilish Zdani'I. [Ensuring Reliability of the Underground Part of the Residential Buildings Complex]. Zhilishnoe Stroitelstvo. 2012. No 9. 38-42.
- Makovetsky OA Tsidvintseva MS, KO Makovetskaya. Ustroistvo Konstrukcii Podzemnoi Chasti Administrativnogo Zdaniya G. Perm. [The Device Structures of Underground Part of the Administrative Building in Perm City]. Vestnik Volgogradskogo Gosudarstvennogo Universiteta. Seriya: Stroitel'stvo I Arhitektura. 2008. No 10. 143-147.
- Nazarov G.N., Shemshurin V.A. Application of Engineering and Geological Properties in Seismic Microzoning. Seismic Microzoning. M., Science, 1977.
- Rehbinder, G. The Drag Force on the Grains in a Permeable Medium Subjected to a Water Jet. Journal of Applied Mathematics and Physics (ZAMP). Vol. 28, 1977.
- Ter-Martirosyan Z.G., Strunin P.V. Usilenie Slabih Gruntov V Osnovanii Fundametnih Plit S Ispolzovaniem Tehnologii Jet-Grouting. [Strengthening Soft Soil at the Base of the Foundation Plates with Jet-Grouting Technology]. Vestnik MGSU No 4, 2010.
- Zege S.O. Broid I.I. 2004. Konceptii Fizicheskikh Osnov Struinogo Zakrepleniya Gruntov. [Concepts of the Physical Foundations of Jet Grouting]. Osnovaniya, Fundamenti I Mehanika Gruntov, No 2.



Galina G. Kashevarova, Born in Perm, Russia, June 03, 1948.

Academic education: Dr. Sc., Professor in Mathematical Modeling, Numerical Methods and Structural Mechanics, Perm National Research Polytechnic University, Department of Mechanics and Computational Technologies, Perm, Russia, 2005; Ph.D in Dynamics and Strength of Machines, Perm State Technical University, Perm, Russia, 1980; Graduated Dynamics and Strength of Machines, Perm Polytechnic Institute, 1972.

Main activities: Research in the fields of Processes of Deformation and Fracture of the system "Building-Foundation-Soil", Safety of Buildings and Structures.

Educative activities: Professor in the following subjects: Structural Mechanics, Computer-Aided Design in Construction, Numerical Methods; at the post-graduate studies for the degree of master and doctor of technical

sciences: Methodology of Scientific Research, Safety of Buildings and Structures, Settlement Software Systems in the Design of Buildings.

MEMBERSHIP

- Russian Academy of Architecture and Construction Science (RAASN) Advisor;
- Member of the Scientific Council RAASN "Software for construction and architecture";
- Honored Worker of Higher Professional Education of the Russian Federation.



Oleg A. Makovetsky Born in Perm, Perm State, January 11 1961.

Academic education: Ph.D in Soil Mechanics, Perm State Research Polytechnic University, Perm, 1990; Civil Engineer 'Industrial and Civil Engineering and Building Construction', Faculty of Building Design and Construction; graduated from the Perm National Research Polytechnic University in 1983.

Main activities: Associate Professor at Department of

Building Production and Geotechnics, Perm National Research Polytechnic University. Research in the fields of Reliability of the 'ground-foundation'building' system; Methods of Design and Construction of Artificially Improved Grounds.

Educative activities: Professor in the subjects: 'Engineering Geology', 'Soil Mechanics', 'Grounds and Foundations'.



Ilgiz I. Khusainov Born in Perm, Perm State, Russian Federation, May 15, 1988.

Academic education: Civil Engineer 'Industrial and Civil Engineering and Building Construction', Faculty of Building Design and Construction, graduated from the Perm National Research Polytechnic University in

2009.

Main activities: Ph.D student at the Department of Mechanics and computational technologies. Research in the field of Design of Artificially Improved Grounds

Educational activities: Teacher in the subject 'Structural Mechanics'.